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Effect of summer-fall deficit irrigation on morpho-physiological, anatomical responses, fruit yield and water use efficiency of cucumber under salt affected soil

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ABSTRACT

Agriculture has been adversely affected by low water availability due to climate change, creating abiotic stress conditions for economically important crops such as cucumber. Two on-field seasons study (summer and fall) were conducted consecutively in 2016/17 to investigate the effect of deficit drip irrigation at three levels ($DI_{0\%}$ = 100%, $DI_{20\%}$ = 80%, and $DI_{40\%}$ = 60% of crop evapotranspiration) on cucumber's growth and productivity, water use efficiency (WUE), osmo-protectants, leaf photosynthetic pigments and chlorophyll *a* fluorescence, plant water status, and leaf anatomy. Results showed that, fall season exceeded summer season in growth characteristics and fruit yields, WUE, soluble sugars, leaf photosynthetic pigments, plant water status (RWC and MSI), and leaf anatomy characteristics, while harvest index (HI), free proline and chlorophyll fluorescence were higher in summer than fall. For DI, with some exceptions all the aforementioned parameters were similar, approximately, under both $DI_{0\%}$ and $DI_{20\%}$. Under $DI_{40\%}$, values of all aforesaid parameters showed significant reductions compared to those recorded under $DI_{0\%}$ and $DI_{20\%}$, except for WUE, which was increased as DI increased. Therefore, intensive cultivation of cucumber in fall season will save more water with application of $DI_{20\text{-}40\%}$ according to the availability of water in the region, total fruit yield, and fruit price from which a decision to select either $DI_{20\%}$ or $DI_{40\%}$ of irrigation water applied (IWA) will be made.

1. Introduction

Cucumber (*Cucumis sativus* L.) is one of the most important vegetable crops cultivated worldwide. In arid and semiarid areas including Egypt, water scarcity is the major limiting factor in agricultural production. Sustainable agricultural practices, including better understandings of water productivity are considered to be a successful management tool under water-limited environments (Bacon, 2004; Howell, 2001). Deficit irrigation (DI), irrigation by water amounts less than the optimum crop water requirements, is a common sustainable practice in many regions of the world (Pereira et al., 2002). The potential benefits of DI derive from two major factors: increased water use efficiency and reduced costs of irrigation either by reducing the amount of irrigation water or by reducing the number of irrigation events (Igbadun et al., 2012; Patane et al., 2011). Effects of deficit irrigation on many vegetables and field crops growth and productivity have been reported by several researchers (Abd El-Mageed et al., 2016a, 2016b; Badal et al., 2013; Ballester et al., 2011; Karam et al., 2011). DI increased water productivity with no severe yield reduction to be caused for different crops (Geerts and Raes, 2009; Semida et al., 2017). On the other hand, it has been reported that cucumber yield decreased in linear relationship with the increase of DI (Amer et al., 2009). Cucumber yield was significantly affected by irrigation water amount at all growth stages. The least productive irrigation regimes were those that had water deficiencies during fruiting stages (Mao et al., 2003). In hydroponically cultivated zucchini, marketable fruits and total yields as well fruit number and weight plant^{-1} were considerably affected by growing season and irrigation system but not by their interaction. They added that lower yield observed in summer and/or fall growing season was attributed to a decrease in fruits weight and number (Rouphael and Colla, 2005). In another study on summer and fall squash, water productivity was affected by deficit irrigation and growing seasons. Water use efficiency was higher under fall season when compared with summer season (Abd El-Mageed and Semida et al., 2015a). In addition, Al-Omran et al., (2005) reported that squash yield were considerably affected by increasing the amounts of irrigation water. They added,

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WUE was increased in general with a reduction in the amount of irrigation water, but it was decreased at full irrigation level. WUE increased linearly as irrigation water applied increased; however, the various effects of deficit irrigation are crop-specific. Thus, to adapt a given crop to a specific location it is essential to assess the effect of different deficit irrigation strategies through multi-years open field experiments, before generalizing the most appropriate irrigation scheduling method (Abd El-Mageed and Semida et al., 2015b). Therefore, the main objective of the current study was to evaluate the effect of 20 and 40% deficit irrigation on growth, yields, water use efficiency, and physio-chemical attributes of cucumber plants grown in two (summer and fall) seasons. Results could provide a useful tool for developing a sustainable management strategies for cucumber production with reduced irrigation water.

2. Materials and methods

2.1. Lay out and experimentation

Two on-field seasons (summer and fall) experiments were conducted consecutively in 2016/17 in a private farmer's field, Fayoum, Egypt (latitudes 29° 02´ and 29° 35´ N and longitudes 30° 23´ and 31° 05´ E). The soil, 0.90 –1.0 m deep, is saline loamy sand and defined as Typic Torripsamments, siliceous, hypothermic (Soil Survey Staff USDA, 1999). The chemical and physical characteristics of the soil were: pH 7.79 (1:2.5 soil/water extract), Kjeldahl total N 1.38 g kg^{-1}, Olsen extractable P 524.7 mg kg^{-1}, ammonium acetate extractable K 44.3 mg kg^{-1}, organic C 8.0 g kg^{-1}, total carbonate 191.7 g kg^{-1}, electrical conductivity (EC_e; soil paste extract) 8.23 dS m^{-1}, bulk density 1.62 kg dm^{-3}, and water content at field capacity and wilting point 24 and 11%, respectively. Based on the EC value (8.23 dS m^{-1}), the soil is classified as being saline according to Dahnke and Whitney (1988).

Three irrigation levels of evapotranspiration (ETc) were investigated in both (summer and fall) season. They were: $DI_{0\%}$ = irrigation at 100% of ETc (control), $DI_{20\%}$ = deficit irrigation water was 80% compared to the control irrigation regime, and $DI_{40\%}$ = deficit irrigation water was 60% compared with the control regime. The total amounts of irrigation water applied during summer season were 3970, 3176 and 2382 $m^3\,ha^{-1}$, and were 2920, 2336 and 1752 $m^3\,ha^{-1}$ for fall season for $DI_{0\%}$, $DI_{20\%}$, and $DI_{40\%}$, respectively. The experimental lay out was a Randomized Split Plot design with three replicates for each treatment.

The area of each experimental plot was 13.2 m^2; 12 m length × 1.10 m row width and about 0.3 m between plants within rows. Seeds of Cucumber hybrid Hayl® were sown 0.05 m away from the drip line at a depth of 0.04 m, drip irrigated with one line and one dripper per plant giving 4.0 L h^{-1}. Treatments were separated by 1 m non-irrigated area. Cucumber seeds were planted on May 20th and October 3rd, and terminated on August 6th and January 1st in the 2016/17 summer and fall seasons, respectively. One week after full germination different irrigation treatments were initiated. Fertilizers rate of application and other agricultural practices were according to the recombination of the Agricultural Research Center, Cairo, Egypt.

Cucumber plants were irrigated at 2 d intervals by different amounts of irrigation water treatments. According to the assessments with class A pan equation (ETo), Irrigation water applied (IWA) was determined as a percentage of the potential evapotranspiration representing one of the following three treatments: $DI_{0\%}$ = 100%, $DI_{20\%}$ = 80% and $DI_{40\%}$ = 60% of ETc. Daily ET_0 was computed using the pan equation as follows:

$$ET_o = E_{pan} \times K_{pan} \tag{1}$$

Where: ET_O is the reference evapotranspiration (mm/day), E_{pan} is the evaporation from the Class A pan (mm. d^{-1}), and K_{pan} is the Pan Coefficient (FAO pp. No. 24).

The crop water requirements (ETc) were estimated using the crop coefficient according to the following equation:

$$ET_c = ET_o \times K_c \tag{2}$$

Where etc is the crop water requirement (mm. d^{-1}) and Kc is the crop coefficient. The duration of the different crop growth stages were 20, 30, 40, and 15 d for initial, crop development, mid-season and late season stages, respectively and the crop coefficients (Kc) of initial, mid and end stages were 0.60, 1.00 and 0.95, respectively, according to Allen et al. (1998).

The quantification of IWA for each treatment was done during the irrigation regime by using the following equation:

$$IWA = \frac{A \times ETc \times Ii \times Kr}{Ea \times 1000 \times (1 - LR)} \tag{3}$$

Where IWA is the irrigation water applied (m^3), A is the plot area (m^2), etc is the crop water requirements (mm. d^{-1}), Ii is the irrigation intervals (d), Ea is the application efficiency (%) (Ea = 85), Kr is the covering factor and LR is the leaching requirements.

2.2. Observation

Soil water content was recorded every 2 days at 0–15 and 15–30 cm depth using digital moisture meter sensors (HH2 type, Cambridge, CB5 0 EJ, UK). Five plants from each experimental plot were randomly chosen, at the end of each season, to determine plant growth characteristics, physio-chemical attributes and leaf anatomy. All plants of each experimental unit were used to measure yield and its components.

Plant leaf area was measured using Planix 7 Planometer (Tamaya Technics Incorporated). Shoots of plants were weighed for their fresh weights. For dry weight, shoot were placed in an oven at 70 ± 2 °C until a constant weight was recorded. Chlorophyll *a* fluorescence was measured using a handy PEA chlorophyll fluorometer (Hansatech Instruments Ltd, UK). F_v/F_m, the maximum quantum yield of PS II, was calculated from the equation: $F_v/F_m = (F_m - F_o)/F_m$ (Maxwell and Johnson, 2000). PI, performance index of photosynthesis based on the equal absorption, was calculated as illustrated by Clark et al., (2000). Third fully expanded leaves sample from top were chosen randomly from each treatment to conduct the physiological measurements i.e., free proline, total soluble sugar, and leaves relative water content (LRWC). Free proline concentrations was determined using the colorimetric method of Bates et al., (1973). The ethanolic method described by Irigoyen et al., (1992) was used to determine the concentration of total soluble sugar in leaves.

Plant water status was evaluated by measuring leaves relative water content (LRWC) as described by (Hayat et al., 2007). Leaf tissue samples (0.2 g) of fully-expanded leaves were used to determine the membrane stability index (MSI) as described by Rady, (2011). Harvest index (HI) was determined as a ratio of total fruit yield to the plant total biomass on a dry mass basis. The ratio of fruit yield (kg) to respective water use (m^3) was calculated and expressed as water use efficiency (WUE) in kg $ha^{-1}mm^{-1}$ (Jensen, 1983).

2.3. Statistical tests

Data collected during the two seasons (summer and fall, 2016/17), and a combined analyses were run over seasons. A simple analysis of variance (ANOVA) was carried out by Genstat statistical package (VSN International Ltd, Oxford, UK). Means multiple comparisons were done by least significant difference (LSD) test at 0.05 and 0.01 probability.

3. Results

Regarding climatic data of the two experimental seasons shown in Table 1 and Fig. 1 maximum daily temperatures during summer season averaged between 33.1 and 29.4 °C, and maximum daily temperatures during fall season averaged between 30.1 and 23.3 °C. The air relative

Table 1
Monthly weather data at Fayoum, Egypt during 2016/2017 summer and fall growing seasons.

Month	T_{min}[a] (∘C)	T_{max} (∘C)	T_{avg} (∘C)	RH_{avg} (%)	U_2 ms^{-1}	E_p mmd^{-1}
May	21.43	37.36	29.39	41.68	1.90	6.49
June	23.43	39.48	31.45	42.73	1.50	8.30
July	25.07	40.92	33.07	41.22	2.00	7.50
August	25.20	38.10	31.60	49.50	1.60	6.80
September	23.60	36.6	30.10	43.70	2.10	5.80
October	19.54	30.79	25.11	43.03	2.00	4.18
November	17.47	29.13	23.32	40.53	2.20	2.54
December	9.50	21.00	15.30	42.00	1.62	1.50

[a] T_{avg}, T_{max}, and T_{min} are average, maximum, and minimum temperatures, respectively, RH_{avg} is average relative humidity, U_2 is average wind speed, and E_P is average of measured pan evaporation class A.

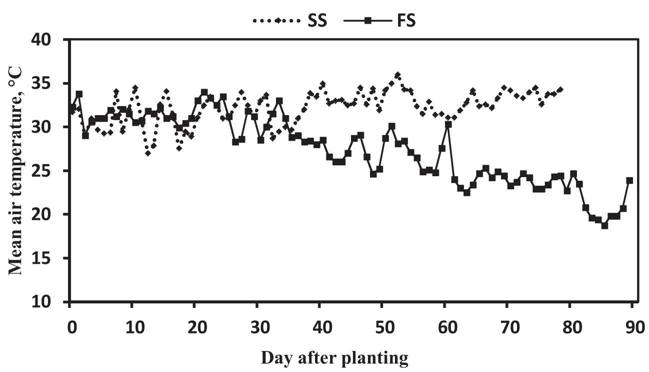

Fig. 1. Degrees of mean air temperatures recorded during irrigation cropping seasons (summer and fall).

humidity averaged between 41.2 and 49.5% in summer season and averaged between 40.5 and 43.7 in fall season. Pan evaporation averaged between 6.5–8.3 mm d^{-1} and 2.5 and 5.8 mm d^{-1} in summer and fall season seasons respectively.

For experimental seasons, data obtained show that fall season exceeded summer season in growth characteristics (shoot length, leaves number $plant^{-1}$, leaves area, shoot fresh and dry weight; (Table 2) and fruit yield and its components i.e., fruit number $plant^{-1}$, average fruit weight and fruit yield ha^{-1}; Table 3. The interactive effect of deficit irrigation and growing seasons on shoot dry weight, shoot fresh weight, leaves area plant-1, number of leaves plant-1 and shoot length were statistically analyzed as shown in Fig.2. The highest plant growth attributes had been recorded when cucumber plants were subjected to full irrigation (I100) or deficit 20% and planted in the FS. However, the lowest values were obtained under water-deficit conditions (I40) in the

Table 2
Effect of growing season and deficit irrigation on growth characteristics of cucumber plants grown under saline soil conditions.

Source of variation	Shoot length (cm)	Number of leaves $plant^{-1}$	Leaves area $plant^{-1}$ (dm^2)	Shoot fresh weight (g)	Shoot dry weight (g)
Season (S)	NS	NS	**	**	**
Summer	95.3	34.5	55.7[b]	208.2[b]	22.3[b]
Fall	105.1	35.3	76.9[a]	288.4[a]	30.7[a]
IWA	**	*	**	**	**
$DI_{0\%}$	108.8[a]	44.1[a]	82.9[a]	218.2[b]	26.3[b]
$DI_{20\%}$	112.5[a]	46.0[a]	73.1[b]	282.3[a]	32.6[a]
$DI_{40\%}$	89.3[b]	24.6[b]	42.9[c]	169.8[c]	19.2[c]
S × IWA	**	*	**	**	**

** and * indicate respectively differences at $P \leq 0.05$ and $P \leq 0.01$ probability level, and "ns" indicates no significant difference. Means followed by the same letter in each column are not significantly different according to the LSD test ($P \leq 0.05$).

Table 3
Effect of growing season and deficit irrigation on yields, harvest index (HI %) and water use efficiency (WUE) of cucumber plants grown under saline soil conditions.

Source of variation	Fruit number $plant^{-1}$	Fruit weight (g)	Fruit yield (Mg ha^{-1})	HI (%)	WUE (Kg m^{-3})
Season (S)	**	NS	**	*	**
Summer	3.58[b]	84.70	10.37[b]	0.71[a]	4.06[b]
Fall	5.58[a]	85.80	14.84[a]	0.64[b]	6.65[a]
IWA	**	*	*	**	*
$DI_{0\%}$	5.54[a]	94.60[a]	14.25[a]	0.77[a]	4.62[b]
$DI_{20\%}$	5.21[a]	86.00[b]	13.67[a]	0.71[b]	5.08[ab]
$DI_{40\%}$	3.00[b]	75.20[c]	9.89[b]	0.53[c]	6.36[a]
S × IWA	*	NS	*	NS	*

** and * indicate respectively differences at $P \leq 0.05$ and $P \leq 0.01$probability level, and "ns" indicates not significant difference. Means followed by the same letter in each column are not significantly different according to the LSD test ($P \leq 0.05$).

SS. Impact of the interaction of DI and growing season on fruit number plant-1, fruit weight, fruit yield, harvest index (HI) and WUE were statistically analyzed as shown in Fig.3. They were significantly or insignificantly affected by the interaction of season and DI. The results showed that fruit weight and HI were not significantly affected by the interaction between season and DI. On the other hand, number of fruits plant -1 fruit yield (Mg ha − 1) and WUE (Kg m − 3) were significantly affected at P ≤ 0.05. The highest WUE value was recorded when cucumber plants were subjected to DI40% under FS (7.97 kg m-3). This may be due to that IWA of cucumber in SS was higher by than FS due to increasing air temperature during SS as shown in (Fig. 1). The increases were 10.3% for shoot length, 2.3% for leaf number per plant, 38.1% for plant leaves area, 38.5% for shoot fresh weight, 37.5% for shoot dry weight, 55.9% for fruit number per plant, 1.3% for average fruit weight, and 43.1% for fruit yield per hectare. In addition, WUE (Table 3), soluble sugars, leaf photosynthetic pigments (Table 4), MSI, RWC (Table 5) and leaf anatomy characteristics (Table 6 and Fig. 4) were significantly increased in fall season compared to summer season. The increases were 63.8% for WUE, 4.7% for soluble sugars, 16.9% for leaf photosynthetic pigments, 12.5% for MSI, and 3.1% for RWC. In contrast, harvest index (HI), free proline and chlorophyll fluorescence were higher in summer than fall season.

For deficit irrigation (DI), the all aforementioned parameters were similar, approximately, under both DI at 0% ($DI_{0\%}$) and DI at 20% ($DI_{20\%}$), except some fluctuations. Under DI at 40% ($DI_{40\%}$), values of all aforesaid parameters showed significant reductions compared to those recorded under $DI_{0\%}$ and $DI_{20\%}$, except for WUE, which was increased gradually with increasing DI.

4. Discussion

In the year of 2016, weather data presented in Table 1 show that

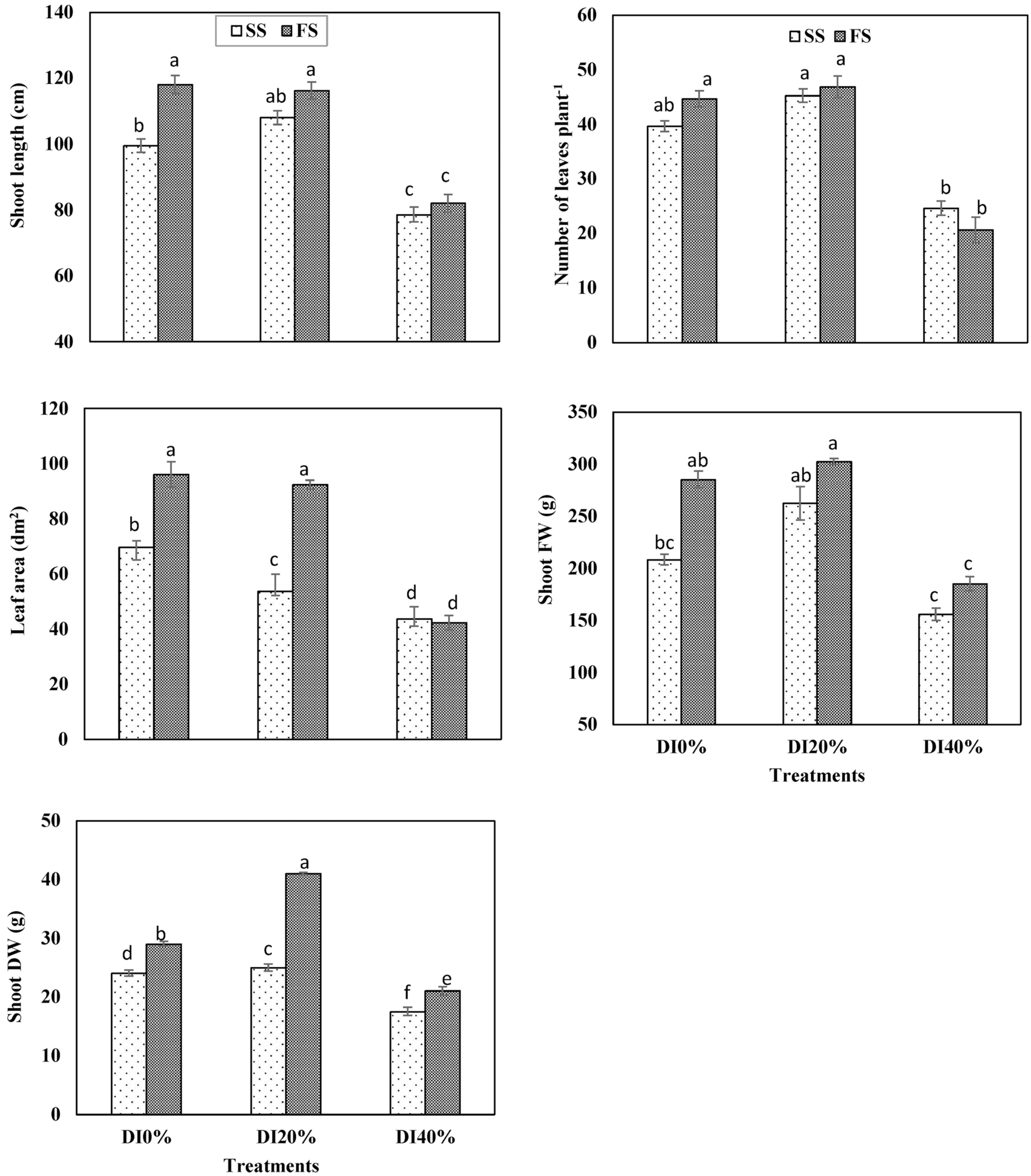

Fig. 2. Interactive effects of growing season and deficit irrigation on growth characteristics of cucumber under saline soil conditions.

average daily temperatures recorded during summer season were higher than those recorded during fall season. Fig. 1 shows the differences of maximum daily temperatures during both seasons. In contrast, average relative humidity recorded during fall season was higher than that recorded during summer season. Therefore, it has been concluded that the total amount of IWA during summer season were considerably higher (i.e., 3970, 3176 and 2382 m^3 ha^{-1} for; $DI_{0\%}$, $DI_{20\%}$, and $DI_{40\%}$, respectively) than those applied during fall season (i.e., 2920, 2336 and 1752 m^3 ha^{-1} for; $DI_{0\%}$, $DI_{20\%}$, and $DI_{40\%}$, respectively). The decrease in the amounts of IWA in fall season was accompanied with the higher growth characteristics and yields of cucumber plants as well as water use efficiency (Tables 2 and 3), particularly with the application of 80% ($DI_{20\%}$) of ETc for cucumber. Additionally, according to Abd El-Mageed and Semida et al., 2015b, ECe of the tested soil may be reduced due to that drip irrigation that is known to conduct over a long period of time with low rate of discharge and high frequency which can maintain constant and high soil water contents in the rhizosphere. This may be led to a reduction in the soil water salinity levels by leaching, mostly near the drip emitters and reduce deep percolation, as shown in the results of Elfving (1982), and Keller and Bliesner (1990). During drip-irrigation, salts in the soil tend to move with the water to the fringes of the wetted area, providing a reduced osmotic potential which alleviate the osmotic stress effect on plant growth (Abd El-Mageed and Semida et al., 2015b). Some recent studies have reported a positive effects of drip irrigation on crop yield and salt leaching (Chen et al., 2010; Hou et al., 2009). In addition, another study has focused on the effects of

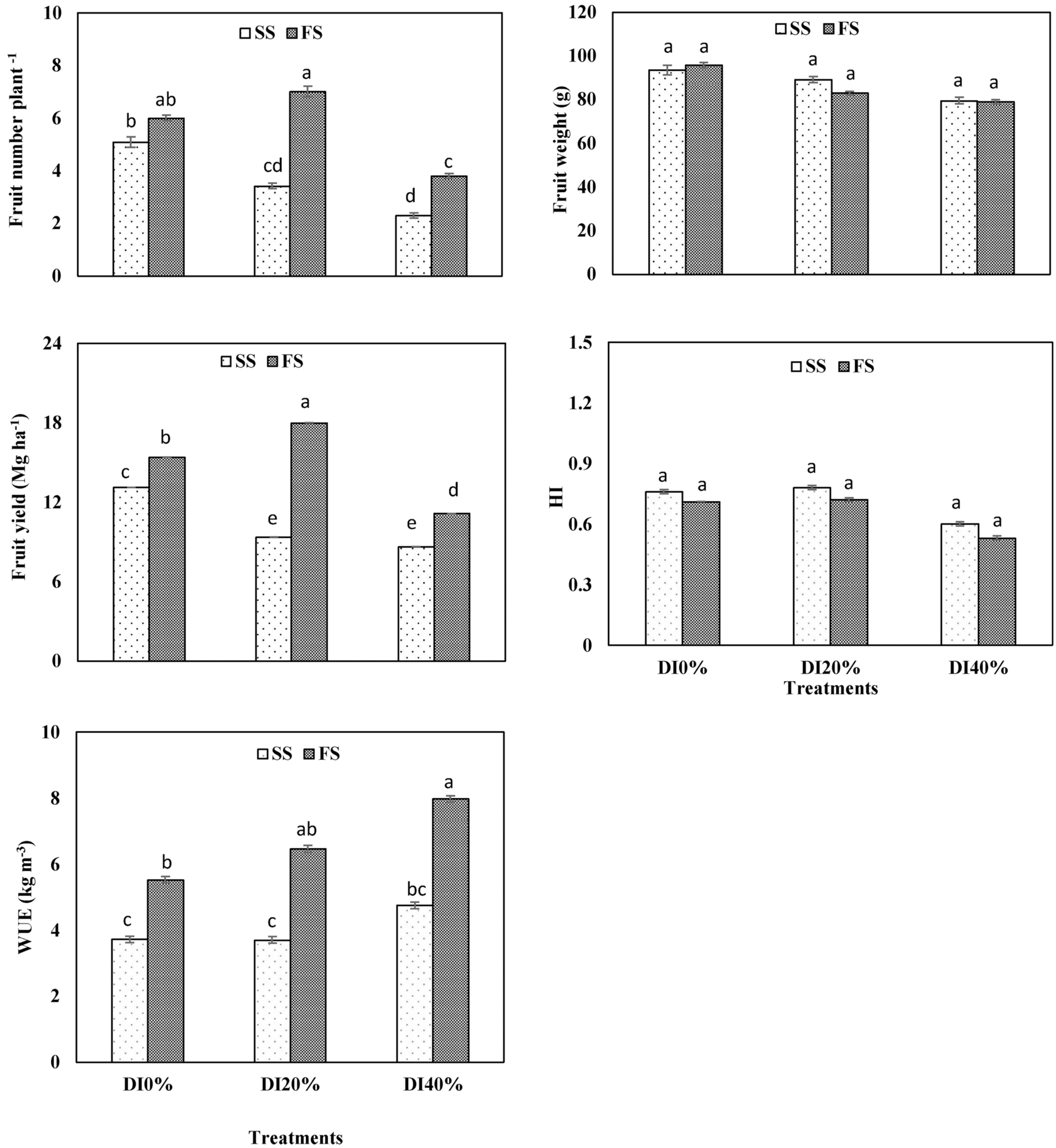

Fig. 3. Interactive effects of growing season and deficit irrigation on harvest index (HI), fruit yield, fruit quality and water use efficiency (WUE) of cucumber under saline soil conditions.

different levels of soil matric potential (SMP) on salt distribution in the soil and consequently on crop growth, and found that the very strongly saline soil gradually changed to a moderately saline soil after cultivation for 2–3 years (Wang et al., 2011).

Growth characteristics and yield values in cucumber plants of fall season were considerably higher than those of summer season (Tables 2 and 3), while harvest index (HI) recorded under fall season was lower than that recorded under summer season (Table 3) in contrast with that obtained by Amer, (2011) on squash. The increase of growth and yield of cucumber occurred in fall season may be due to lower temperatures conditions which were suitable for growing cucumber than those of summer season. Wan et al., (2012) on cucumber and Amer, (2011) and Abd El-Mageed and Semida et al., 2015b on squash reported that the lower yields obtained in summer season were due to non-favorable weather, which conformed to the results of this study as shown in Table 1. Maximum cucumber yields recorded in fall season could be attributed to the increase in number of fruit plant^{-1} than those obtained in summer season (Table 3). Regarding the IWA, in conformity to the present study results, Abd El-Mageed and Semida et al., 2015b and Amer, (2011) reported significant effects of IWA on plant growth and productivity, where maximum yield values were recorded when plants were fully irrigated ($DI_{0\%}$), while the minimum values of yields were generated with the lowest IWA ($DI_{40\%}$). But no significant differences between cucumber yields obtained with both $DI_{0\%}$ and $DI_{20\%}$. Cucumber yield increased as IWA increase (Zhang et al., 2011), that may be attributed to the available water amount in the soil under higher level of IWA which enhances different metabolic mechanisms in plants. Irrigation water reduction by 20% from IWA ($DI_{20\%}$) reduced cucumber

Table 4
Effect of growing season and deficit irrigation on the concentrations of leaf photosynthetic pigments, free proline and total soluble sugars in cucumber plants grown under saline soil conditions.

Source of variation	Free proline ($mg\ g^{-1}$ DW)	Soluble sugars ($mg\ g^{-1}$ DW)	Chlorophyll 'a' ($mg\ g^{-1}$ FW)	Chlorophyll 'b' ($mg\ g^{-1}$ FW)	Carotenoids ($mg\ g^{-1}$ FW)
Season (S)	*	*	NS	**	NS
Summer	0.48^a	1.72^b	11.81	9.74^b	1.77
Fall	0.43^b	1.80^a	12.51	12.88^a	1.87
IWA	**	*	*	**	*
$DI_{0\%}$	0.46^b	1.97^a	13.00^a	14.27^a	1.96^a
$DI_{20\%}$	0.49^a	1.77^b	13.36^a	11.59^b	1.84^a
$DI_{40\%}$	0.42^c	1.70^b	10.12^b	8.08^c	1.65^b
S × IWA	NS	NS	NS	NS	*

** and * indicate respectively differences at $P \leq 0.05$ and $P \leq 0.01$probability level, and "ns" indicates no significant difference. Means followed by the same letter in each column are not significantly different according to the LSD test ($P \leq 0.05$).

Table 5
Effect of growing season and deficit irrigation on chlorophyll fluorescence parameters, membrane stability index (MSI %) and relative water content (RWC %) of cucumber plants grown under saline soil conditions.

Source of variation	F_v/F_m	F_v/F_0	PI_{ABS}	MSI (%)	RWC (%)
Season (S)	*	*	*	Ns	NS
Summer	0.83^a	4.74^a	6.60^a	47.30	68.20
Fall	0.79^b	4.09^b	4.14^b	53.20	70.30
IWA	*	*	**	*	*
$DI_{0\%}$	0.83^a	4.89^a	7.02^a	53.20^a	72.90^a
$DI_{20\%}$	0.80^{ab}	4.26^{ab}	4.96^{ab}	46.90^b	71.50^a
$DI_{40\%}$	0.79^b	4.10^b	4.12^b	46.90^b	63.20^b
S × IWA	NS	NS	NS	Ns	NS

** and * indicate respectively differences at $P \leq 0.05$ and $P \leq 0.01$ probability level, and "ns" indicates no significant difference. Means followed by the same letter in each column are not significantly different according to the LSD test ($P \leq 0.05$).

yields at no significant values, but the decrease by 40% from IWA ($DI_{40\%}$) decreased cucumber yields at significant values compared to the $DI_{0\%}$ treatment (Table 3). Logically, the obtained result likely due to the shortage of soil water which adversely disturbs different biological processes i.e., plant bio-dry masses (Table 2), assimilates translocation (Table 4) and photosynthesis (Tables 4 and 5), as well as carbohydrates, amino acids and proteins etc. Cell membrane stability and gas exchange characteristics was adversely affected under drought stress as reported by Hamed (1988) who attributed these results to changed selectivity of water and nutrients as a result of changes in osmotic potentials in plants under drought stress when compared to plants grown under full irrigation conditions.

Under $DI_{0\%}$ (control), $DI_{20\%}$ and $DI_{40\%}$, amounts of IWA for summer season were 3970, 3176 and 2382 $m^3\ ha^{-1}$ and were 2920, 2336 and 1752 $m^3\ ha^{-1}$ for fall season, respectively, saving 20 and 40% water from $DI_{20\%}$ and $DI_{40\%}$ treatments in both seasons. Under water scarcity, therefore, it may be recommended to irrigate cucumber plants at 20% deficit irrigation to produce satisfactory yields at no significantly reductions compared to $DI_{0\%}$ with saving 20% water that equal to 794 $m^3\ ha^{-1}$ during summer season and 584 $m^3\ ha^{-1}$ during fall season.

WUE recorded for fall season was higher than the corresponding WUE of summer season by about 64% (Table 3). This finding may be attributed to that the summer season IWA of cucumber was higher than fall season IWA, due to the increase of air temperatures during summer season as shown in Table 1, solar radiation rate and temperature were positively correlated with transpiration rates of squash plants (Rouphael and Colla, 2005). Additionally, cucumber yields obtained with fall season was higher than the corresponding yields generated in summer season, which may contributed to the WUE. Regarding the effect of IWA, the average values of water use efficiency of $DI_{40\%}$ treatment were higher than those of $DI_{20\%}$, which in turn were higher than those of $DI_{0\%}$ treatment (Table 3). Yaseen et al. (2014) and Abd El-Mageed and Semida et al. (2015b) mentioned that the reduction in irrigation levels found to increase WUE in maize and squash plants, respectively. In general, different studies have proved that lower water applications generated higher WUE values (Abd El-Mageed et al., 2016a; Ertek et al., 2004).

The highest values of chlorophylls and carotenoids, within a growing season, were obtained under no $DI_{0\%}$ (Table 4). The same results were reported on cucumber and cantaloupes by Amer et al., (2009) and Ahmadi-mirabad et al., (2014), respectively. In addition, lower values of chlorophylls and carotenoids were registered in summer season which characterized by a non-favorable weather. This result may be due to the photo-oxidation/destruction of chlorophylls that caused due to high temperatures. Within irrigation levels, chlorophylls and carotenoids were not affected with DI at 20%, but reduced significantly under DI at 40%, which may be attributed to leaf senescence under drought stress. The result of Mäkelä et al., (2000) and Xu and Leskovar, (2014) show that moderate drought stress increased leaf chlorophyll content in tomato, which in part agreed with results of this study (Table 4). They attributed this result to the low irrigation differences between 100 and 60% ETc irrigation. Negative effects of deficit irrigation on chlorophyll *a* fluorescence i.e., F_v/F_m, F_v/F_0 and PI were occurred, particularly under 40% of DI, in both seasons. Higher chlorophyll *a* fluorescence positively reflected in higher yield and sugar content in certain crops. Lower quantum yield associated with a reduction in photochemical efficiency of PSII, could be caused by low

Table 6
Effect of growing season and deficit irrigation on leaf anatomical structure of cucumber plants grown under saline soil conditions.

Treatments	Med vein (μ)		Vascular bundle (μ)		Thickness of blade(μ)	Thick. of palisade tissue(μ)	Thick. of spongy tissue (μ)
	length	width	Length	Width			
Summer							
$DI_{0\%}$	2000a	1650a	875a	550a	280a	130a	110a
$DI_{20\%}$	1800b	1550a	750b	525a	270ab	130a	100a
$DI_{40\%}$	1625c	1375b	625c	400b	250b	110b	100a
Mean	**1808A**	**1525A**	**750**A	**492**A	**267**A	**123**B	**103**A
Fall							
$DI_{0\%}$	1950a	1725a	875a	625a	300a	150ab	110a
$DI_{20\%}$	1925a	1480b	760b	500b	310a	160a	110a
$DI_{40\%}$	1625b	1475b	750b	425b	260b	140b	100a
Mean	**1833**A	**1560**A	**795**A	**517**A	**290**A	**150**A	**107**A

Mean values (n = 5). μ = micron; Measurements were made in 90-day-old plants.

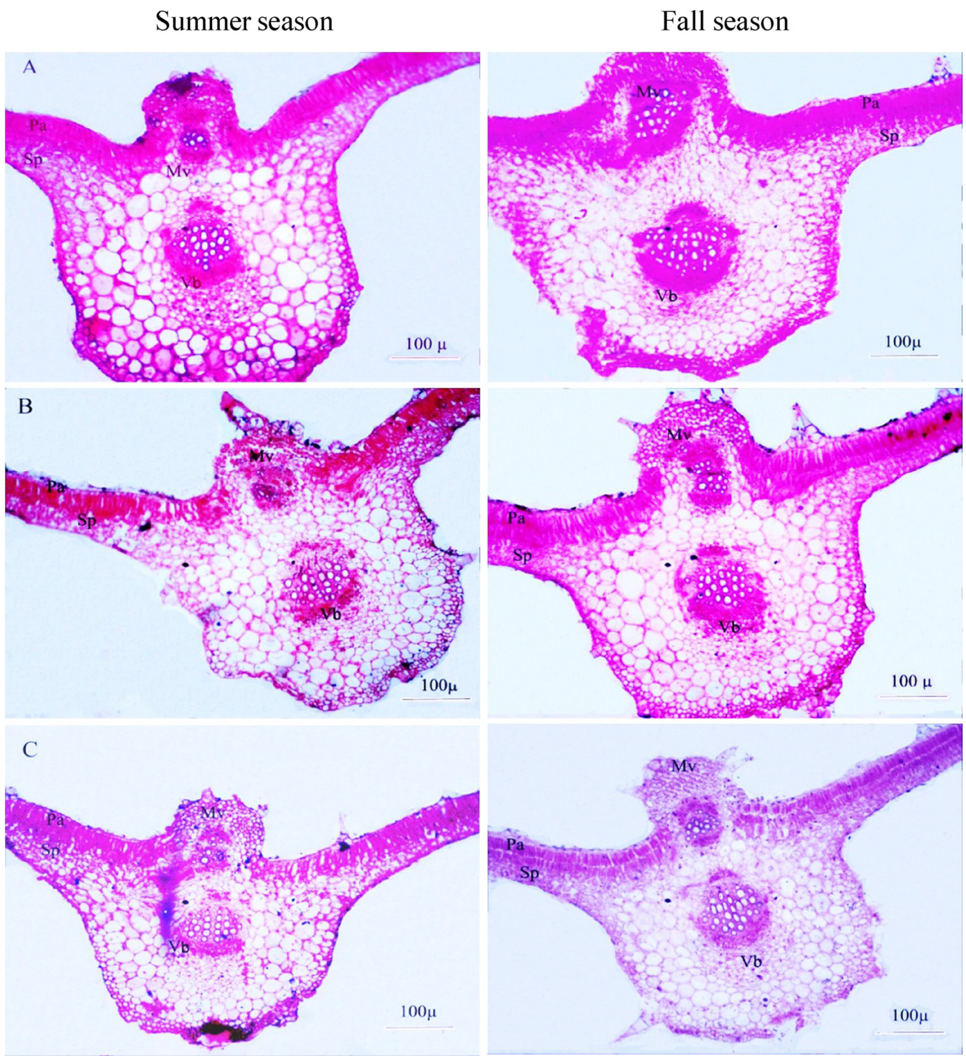

Fig. 4. Leaf anatomy of cucumber plants grown under different irrigation levels and growing seasons. (A) I_{100}, irrigation with 100% of ETc; (B) I_{80}, irrigation with 80% of ETc; (C) I_{60}, irrigation with 60% of ETc; (Mv = mid vein, Vb = Vascular bundle, Pa = Palisade and Sp = Spongy tissue).

photosynthetic activity (Pieters and El Souki, 2005). Reductions in chlorophyll *a* fluorescence parameters of photosystem II (PSII) obtained in the present study under drought stress are possibly due to the reduction in photosynthetic pigments and relative water content (Tables 4 and 5) required for photosynthesis. The reduced photosynthetic pigments concentrations caused due to osmotic stress has been attributed to a strong damage of chloroplast membranes (Kaiser et al., 1981). Habibi (2012) and has also reported a significant reduction in photosynthetic efficiency under water stress, concluding a significant correlation between F_v/F_m and *gs*. This correlation confirmed the idea that, under drought stress, plants limits CO_2 availability for dark reactions through stomatal closure as one of photo-inhibition mechanisms.

Within a growing season, free proline concentration behaved a reverse trend of soluble sugars (Table 4). Maximum proline concentration was found in summer samples, while maximum soluble sugars concentration was obtained in fall samples, indicating that proline may be used by plants as a mechanism against high temperatures in summer season. For irrigation levels treatments, maximum free proline concentration is found to correlate with DI at 20%, while maximum concentration of total soluble sugars is found to relate to DI0% treatment. It was observed that concentration of free proline intensively accumulated in cucumber plants under DI at 20% when stress was in a moderate status. This result may be attributed to the increase in protein breakdown and/or the conversion of some amino acids such as ornithin, arginine and glutamic acid to proline (Chiatante et al., 1999). With accumulation of compatible solutes, osmotic adjustment is accomplished. As one of these cytosolutes, proline tended to accumulate during plant adaptation to various types of abiotic stresses (Oncel et al., 2000).

The effect of growing season on plant water status i.e., RWC and MSI were not significant, no significant difference were also observed between DI at 0% and DI at 20% (Table 5). The result of the current study demonstrate a strong relationship between relative water content and plant biomass (fresh and dry weight) under the combined effect of deficit irrigation and growing season. Cucumber plants with greater biomass can maintain higher leaf water content, thus show more tolerant to DI. Since plant leaves are the main organ of internal water removal, leaf anatomical alterations may be conducted in drought-stressed cucumber plants to save water. In fact, palisade and spongy tissues were affected with DI up to 40%, and consequently thickness of blade (Table 6 and Fig. 4). This could be as a result of enhancing the survival and growth under DI by improving plant water status providing higher protection for plant tissues. This result is found to be in harmony with Bacelar et al., (2004) and Boughalleb and Hajlaoui, (2011). To cope with drought stress, the size of the mesophyll cells of cucumber leaf was decreased. According to Boughalleb and Hajlaoui, (2011), a remarkable leaf anatomical feature observed in olive cultivars grown under water stress was a significant increase in the number of

the epidermal and mesophyll cells. Plant leaves with higher dry matter are more stable mechanically than leaves with lower dry matter and this may be the fundamental cause of their longer life span (Niinemets, 2001). High dry matter in plants support the anatomical studies. Thin spongy parenchyma for plant leaves that probably related to the small volume of mesophyll intercellular spaces that may found in the present study under DI at 20 and/or 40% (Table 6 and Fig. 4) presents anatomical strategy to reduce transpiration.

5. Conclusions

Cucumber plants showed an enhanced growth and productivity particularly under DI at 20% and were almost equal to those produced by well-watered plants, although plant growth and productivity were significantly higher in fall season than summer season. The effective factor in this regard was the water use efficiency (WUE) by cucumber plants that was 64% higher in fall than in summer. Based on plant water status i.e., WUE, RWC, and MSI, the most preferable irrigation level is $DI_{20\%}$, saving 20% of irrigation water applied (IWA). This means, under limited irrigation water, deficit irrigation at 20% can be recommended for commercial cucumber production.

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